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Roughness offset differences between contact and non-contact measurements

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Abstract

An extensive amount of today's research within the field of dimensional metrology is dedicated to multi-sensor and non-contact measurements. Tactile probing on a coordinate measuring machine (CMM) however is inherently different. Although tactile probing is considered more accurate, it often ignores smaller surface details. In essence it means that tactile approaches measure a mechanically filtered surface while the non-contact measurement principles take into account most surface details.

The research presented focuses on the offsets due to surface roughness between touch-trigger probing on a CMM and three non-contact measurement principles (X-ray computed tomography (CT), CMM camera vision and CMM laser line scanning). Results show significantly correlating trends between the offset and the surface roughness.

Keywords: Dimensional metrology, Computed Tomography, CMM, Laser scanning, Vision CMM, Surface roughness, Roughness offset

1. Introduction

Industry nowadays invests in faster and more sophisticated measurement techniques. Apart from tactile probing (touch-trigger and continuous scanning) other novel techniques established themselves. Camera based vision [1], CMM laser scanning [2] and computed tomography (CT) [3] are considered in this paper. Techniques and studies can be found in literature discussing combinations and comparisons [4, 5].

The novel measurement principles are inherently different from tactile probing. Non-contact techniques investigate the surface of an object in another way than tactile probing, which results in extra influencing factors. This paper discusses the influencing factor surface roughness more thoroughly (section 2) and provides experimental results (section 3 to 5).

2. Surface texture and the influence of surface roughness

The texture of a surface is a combination of multiple components. If the real surface is quantified by the vertical deviations to its ideal form a partition can be made based on their wavelength [6]. Figure 1 shows the theoretical division based on wavelength [7] and a linear example. The shorter wavelength, roughness, is neglected by tactile probing but is taken into account by non-contact techniques.

The non-contact measurement methods are especially strong at for instance 3D freeform surfaces, both internally and externally. Primarily freeform production (casting and additive manufacturing (AM)) shows higher surface roughness in their outcome. The measurements conducted with non-contact technologies are thus an optimal choice but their measurement results deviate from the tactile measurement.

Figure 2 sketches the difference in surface definition. The tactile probe cannot reach the valleys of the roughness profile and a non-existent surface boundary is constructed, ignoring a major part of the surface roughness. The non-contact methods however take into account the shorter wavelength component of the surface texture to a better extent and assess the real surface with higher detail. Applying a Gaussian fitting on the captured data results in an offset between both methods.

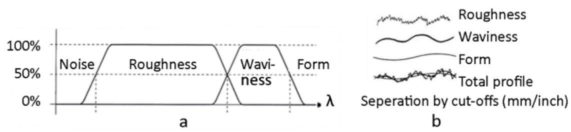

Figure 1. Theoretical approach (a) [7] and example (b) of surface texture partition based on wavelength.

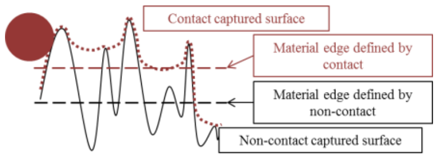

Figure 2. Captured surface for contact and non-contact measurements.

3. CT roughness offset

Three aluminium cylinders are manufactured to examine the roughness dependency of a dimension in a CT measurement, incorporating five sections with an increasing amount of surface roughness (Figure 3). The surface roughness value R_p of all samples varies between 0.40 and 21.60 µm.

Each cylinder is measured with a tactile CMM (Mitutoyo FN905). The tactile measurement consists of 20 evenly distributed measurement points for every cylinder section. In all graphs the average of three repetitions is used. Subsequently, the three cylinders are scanned individually on an industrial X-ray CT scanner (Nikon Metrology XTH 225ST) according to best practices. Each scan is iterated 5 times.

Figure 4a plots the dimensional edge offset of each section of one cylinder against the corresponding surface roughness. R_p is chosen as roughness parameter for its definition of the difference from the midline of the roughness profile to the peaks of the profile (ISO 4287:1997).

The linear trend is not only visible in a single measurement (Figure 4a) but can be found extrapolated over all collected data (Figure 4b). The latter figure applies a numerical bias to both variables, countering CT measurement offsets in between measurement sets. The reference used as bias is respectively the R_p value and the edge offset value of the first section of each cylinder. Two remarks are still important: the values are shown as absolute values and the offset on the diameter measurement is divided by two in the graphs (as the roughness offset has to be applied twice when measuring the diameter). The linear trend across all three objects meets the expectations as all three samples are manufactured using the same tool, thus leaving a similar marking on the surface. The R_p value difference and the corresponding offset difference are encountering a 1:1 ratio.

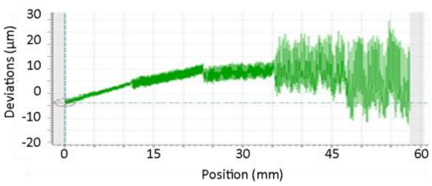

Figure 3. Roughness measurement: 5 sections of increasing roughness.

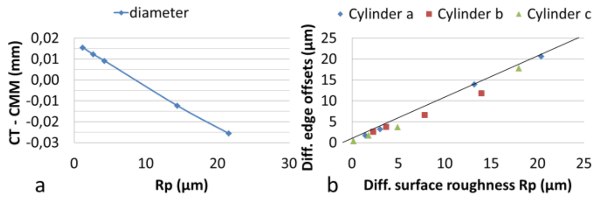

Figure 4. a) Measurement offset between CT and CMM in function of R_p; b) relationship between edge offset and R_p differences in CT.

4. Vision CMM roughness offset

A second non-contact measurement principle of which the roughness offset is described in comparison to a tactile CMM measurement is camera based vision probing (Mitutoyo Quick Vision Pro, CCD camera mounted on a 3D CMM). The experiments are conducted in a similar fashion. Figure 5 depicts a single side measurement. The green crosses indicate the measurement points (±120 per side). Two least square lines are determined: at the top side of the cylinder section and at the bottom side. The perpendicular distance from the centre of gravity of the bound line at the top is then calculated to the bottom line, to obtain the diameter of the cylinder. The average of nine repititions is used for the further results.

The measurement results are processed in a similar manner and also show similar trends (Figure 6a). Yet the trends are less stable. Where the CT measurements show a close to perfect 1:1 ratio, the vision CMM has a lower correlation to this ratio.

Three factors influenced the results. Firstly the measurement is done in a 2D section of the entire cylinder whereas roughness is a statistical parameter that is better estimated the more surface is covered. Secondly the back light projection principle used is not showing the exact section profile, but a shaded profile, due to the roughness not being perfectly aligned to the lighting direction. Lastly the influence of small contaminations like dust particles easily disturb vision measurements, whereas CT is only sensitive to contaminating particles of high density material.

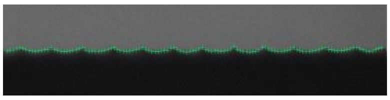

Figure 5. Measurement sample camera based vision system.

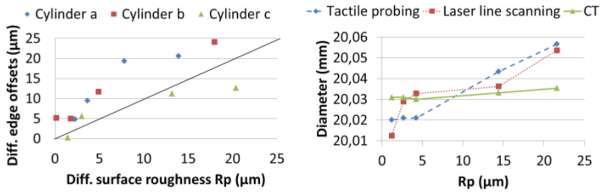

Figure 6. a) Relationship between measurement offset and R_p differences in camera based vision; b) CMM laser scanning results in comparison to the tactile reference and the CT measurement.

5. Laser line scanning roughness offset

The last non-contact technique discussed in this paper is CMM laser scanning (Coord3 MC16 CMM equipped with a Nikon Metrology LC60Dx laser scanner). The measurement uses around 10,000 points per sample section (Figure 3).

Figure 6b displays the CMM laser scanning results of the full point cloud assessment. These results show no distinct trend in comparison to the measured tactile diameter as the other non-contact measurements did.

The standard deviation of each data set is also highly increased with respect to the other measurement techniques (STD_{LLS} = 5 µm; STD_{CT} = 0.5 µm). The main reason is the shiny surface of the roughness samples. The reflective surface resulted in spoiler point patches and a higher noise level. The spoiler point patches can be removed easily, but the higher noise level disturbs the measurements to a high extent. To overcome this problem either a different laser scanner (e.g. LC15Dx) has to be used or a diffuse reflective measurement sample has to be produced.

6. Conclusions

Within this paper first a theoretical explanation is given for the link between the surface roughness and the offset between a contact and a non-contact measurement. The influence of the roughness on the edge offset present has been investigated for three non-contact principles. For CT a high correlation was found. Vision based CMM has a decreased correlation. For CMM laser scanning further investigation is still required. A diffuse reflective roughness sample may show better correlation (less scatter, lower noise).

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